Mutual Impedance experiments: instrumental modelling and tests in plasma chamber

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OUTLINE

1. **The context**:
    a) Mutual impedance experiments
    b) R&D project COMIX
    c) Objectives

2. **Investigation tools**:
    a) Numerical simulations
    b) Plasma chamber

3. **On-going studies and results**:
    a) Effects of large emission amplitudes on mutual impedance experiments
    b) Optimization of mutual impedance antenna occupation time

Instruments for plasma investigation

Mutual impedance probe

Langmuir Probe

QTN

Mass spectrometer

Ion spectrometer

Parameters for plasma characterization

Electron density: n_e

Ion density: n_i

Electron temperature: T_e

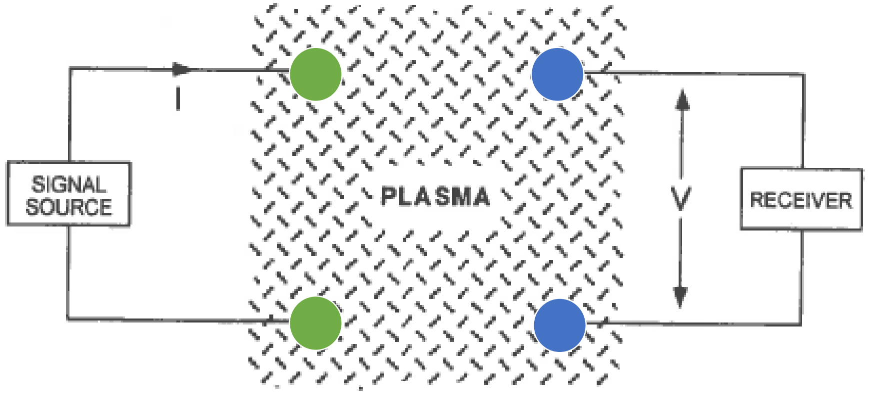
Ion temperature: T_i

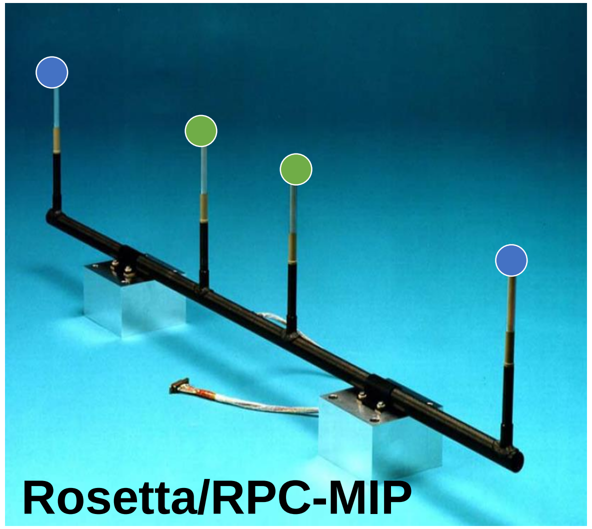
Electron velocity: $v_{D,e}$

Ion velocity: $v_{D,i}$

1) Mutual impedance experiments

Objectives:
Measure in situ ***plasma density*** and ***electron temperature***




Rosetta/RPC-MIP

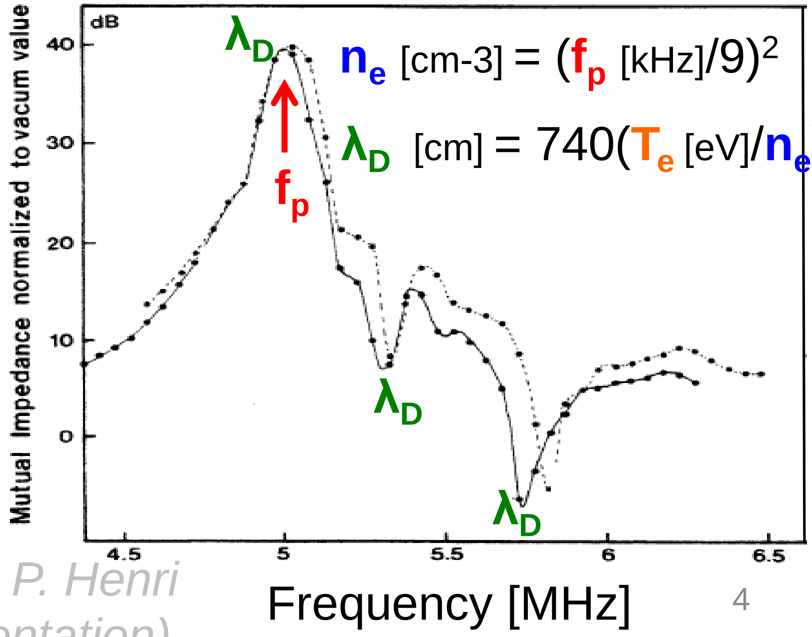
The emission signal:

- Sinusoidal signal
- Fixed amplitude
- Given frequency
- Given amount N of repetitions for each frequency

The reception and data treatment:

- Synchronous analysis (DFT)

Mutual impedance spectrum



n_e [cm-3] = (f_p [kHz]/9)^2

λ_D [cm] = 740(T_e [eV]/n_e)$^{1/2}$

From Arcad-3 [Beghin, 1982]

Mutual impedance experiments on-board recent and future exploratory missions (**Rosetta, BepiColombo, JUICE** and **Comet Interceptor**).

(see P. Henri presentation)

1)COmpact Mutual Impedance eXperiment (COMIX)

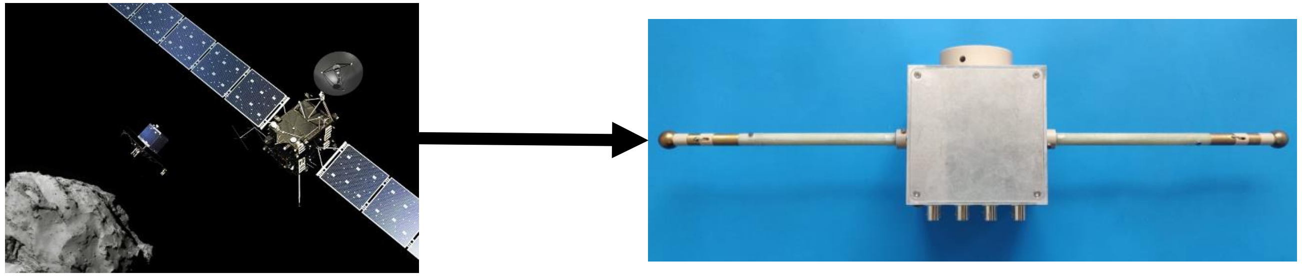
Objective:
Multi-points in situ plasma measurements on-board nanosatellite platforms (space exploration, space weather)

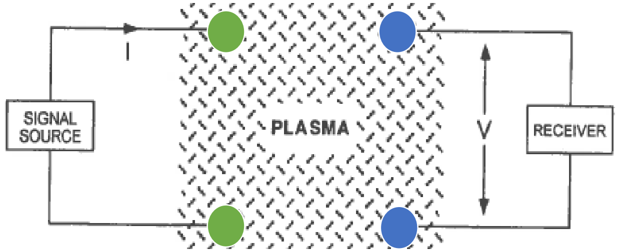
LPC2E

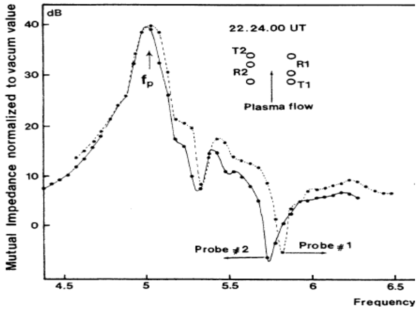
1) Adapt the instrument to nanosatellite platforms

2) New experimental modes

3) Optimize instrument TM through (on-board) data treatment







Funds from CNES

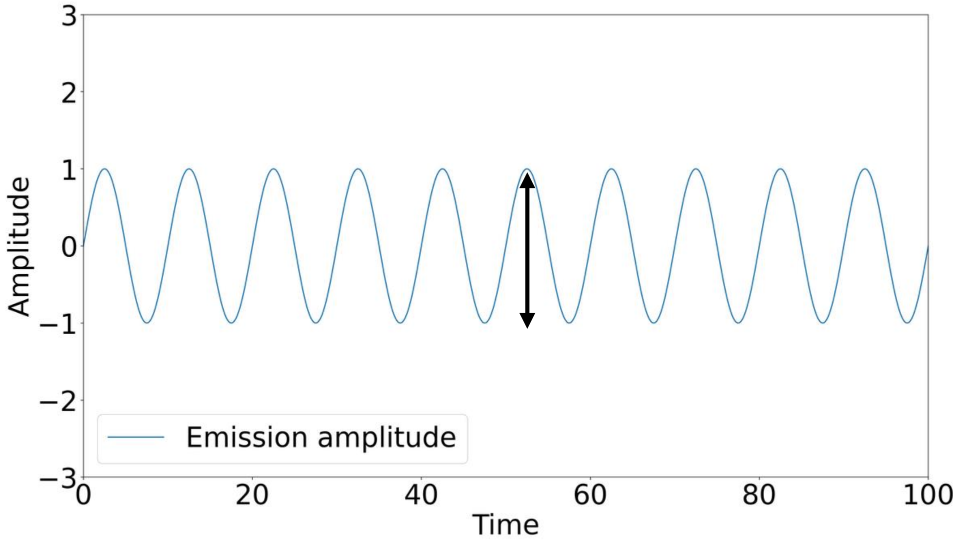
LPC2E
LESIA
IRF, Sweden

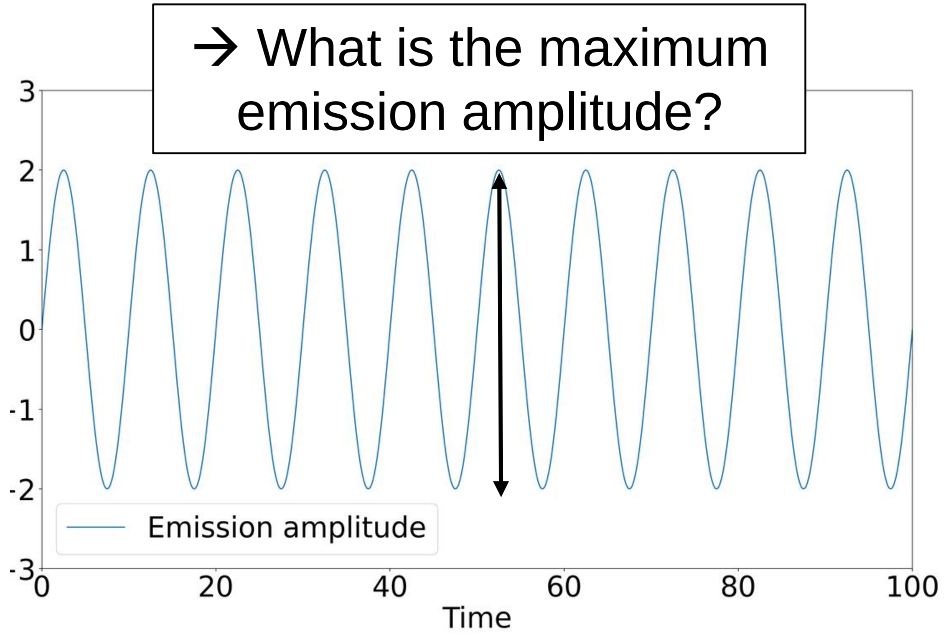
4) Couple the instrument with other plasma instruments
- QTN (K. Issautier, LESIA, Paris Observatory) → *P. Dazzi Thesis*
- Langmuir Probe (IRF, Sweden)

1) Objectives

Objective 1:

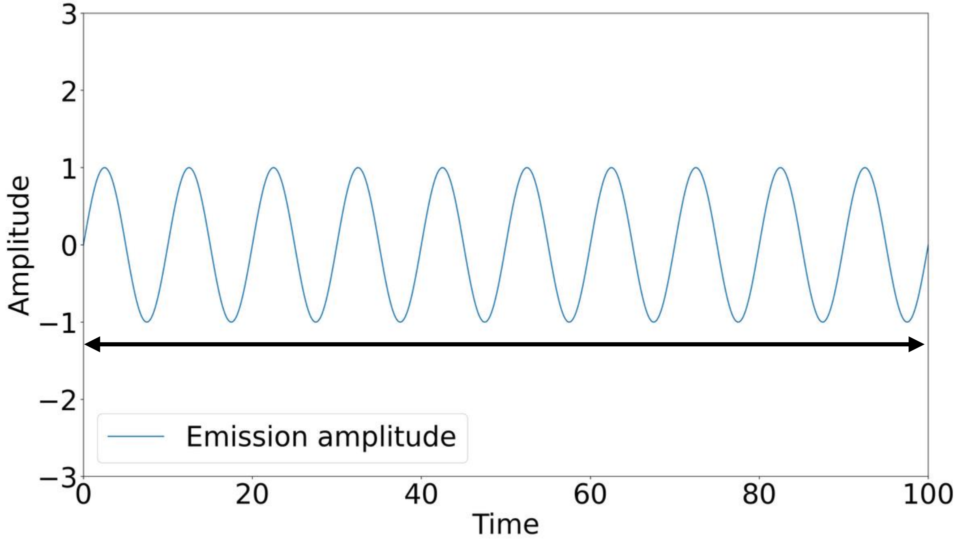
- Improve SNR
- Relax EMC constraints on platform

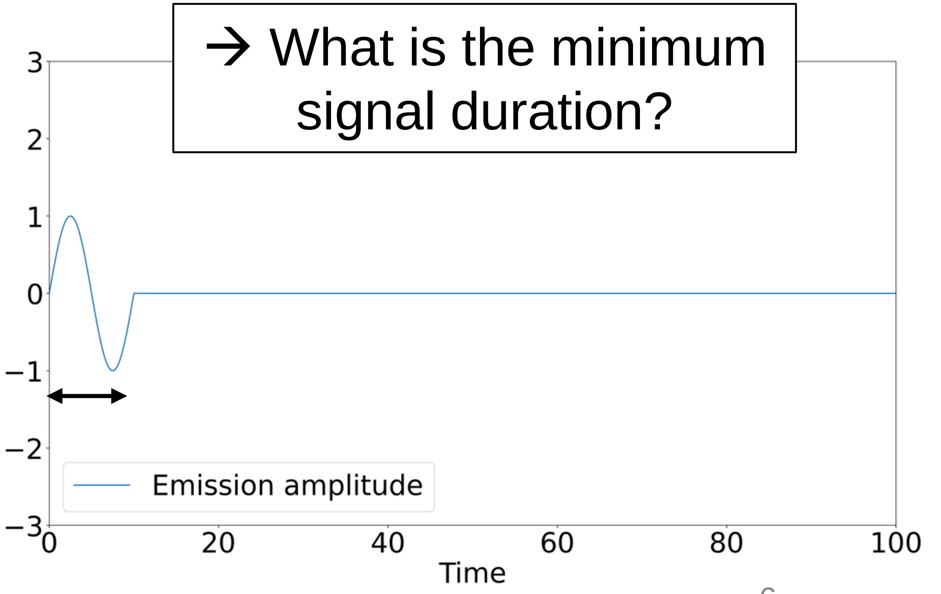



→ What is the maximum emission amplitude?

Objective 2:

- Minimize the antenna occupation time




→ What is the minimum signal duration?

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2) Numerical model & Plasma chamber

Full kinetic Vlasov Poisson 1D-1V
(algorithm from Mangeney et al., 2002)

1D model (computation constraints)
→ **constant** electric field
3D experimental applications
→ electric field **decreases in distance**

- **Plasma populations** ($\alpha = e, p$):

$$\frac{\partial f_\alpha(x,t,v_\alpha)}{\partial t} + \boldsymbol{v}_\alpha \cdot \nabla f_\alpha(x,t,v_\alpha) + \frac{q_\alpha}{m_\alpha}\boldsymbol{E} \cdot \nabla_{\boldsymbol{v}_\alpha} f_\alpha(x,t,v_\alpha) = 0$$

- **External electric antenna**:

$$\nabla \cdot \boldsymbol{E} = -e\frac{n_i(x,t) - n_e(x,t)}{\epsilon_0} - \frac{\rho_{ext.}(x,t)}{\epsilon_0}$$

- Simulated electric field **validated against analytic expressions**
- Simulated spectra **validated against reference spectra**

- **Boundary conditions**:
  - Periodic physical space
  - Distribution functions at zero for ($|v_\alpha| > v_{max}^{-}$)

- Parallelized using OpenMP architecture

2) Numerical model & Plasma chamber

The installation:
- Plasma chamber (L=*2m*, diameter=*1m*)
- Pumping system (vacuum neutral pressure down to *1e-6 mbar*)
- Plasma source (PEPSO project)

Instruments:
- **Langmuir Probe** (reference n_e and T_e)
- Network analyzer
- Keithley
- **Magnetic field compensation system** → *(see P. Dazzi presentation)*
- **Picoscope** (mutual impedance experiments)

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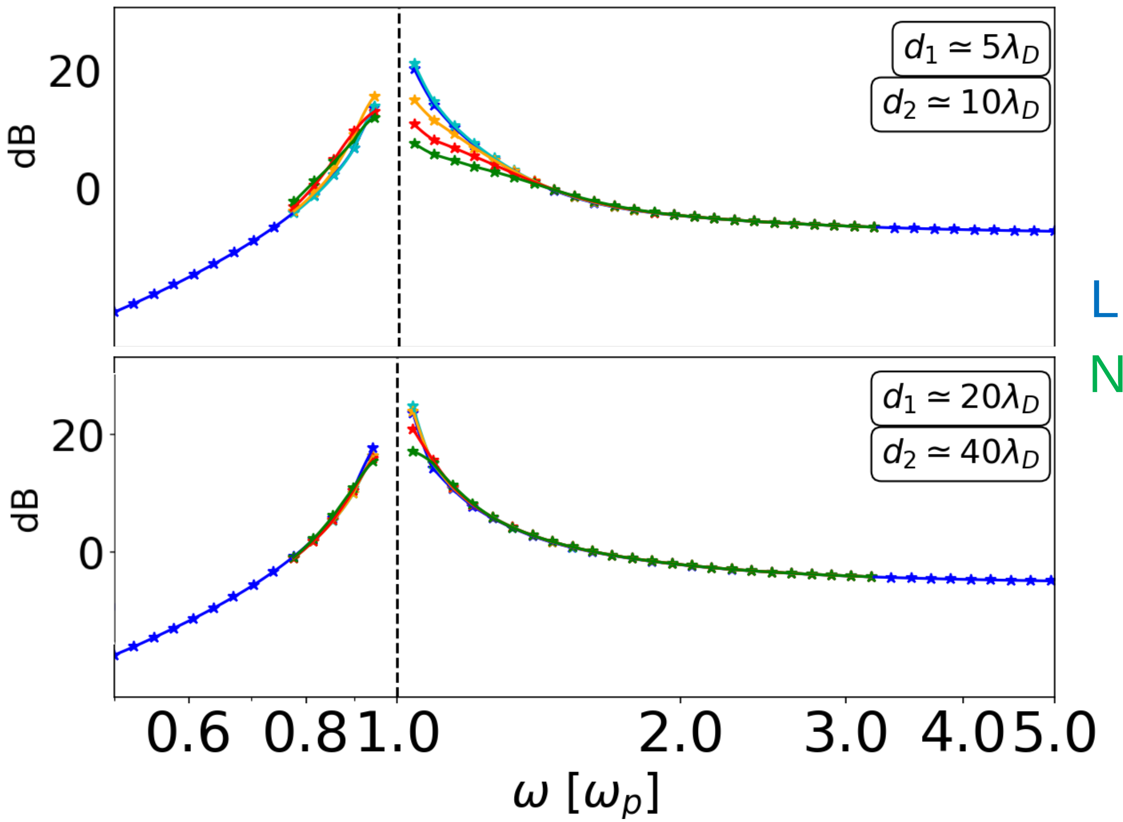
3) Effects of large emission amplitudes

Objective:
Assess the impact of strong emission amplitudes on mutual impedance diagnostic performance

- Numerical investigation
- Spectra **normalized to vacuum**
- Electric-to-thermal energy ratio

$$\frac{E^2\varepsilon_0}{n_0 k_B T_e}$$

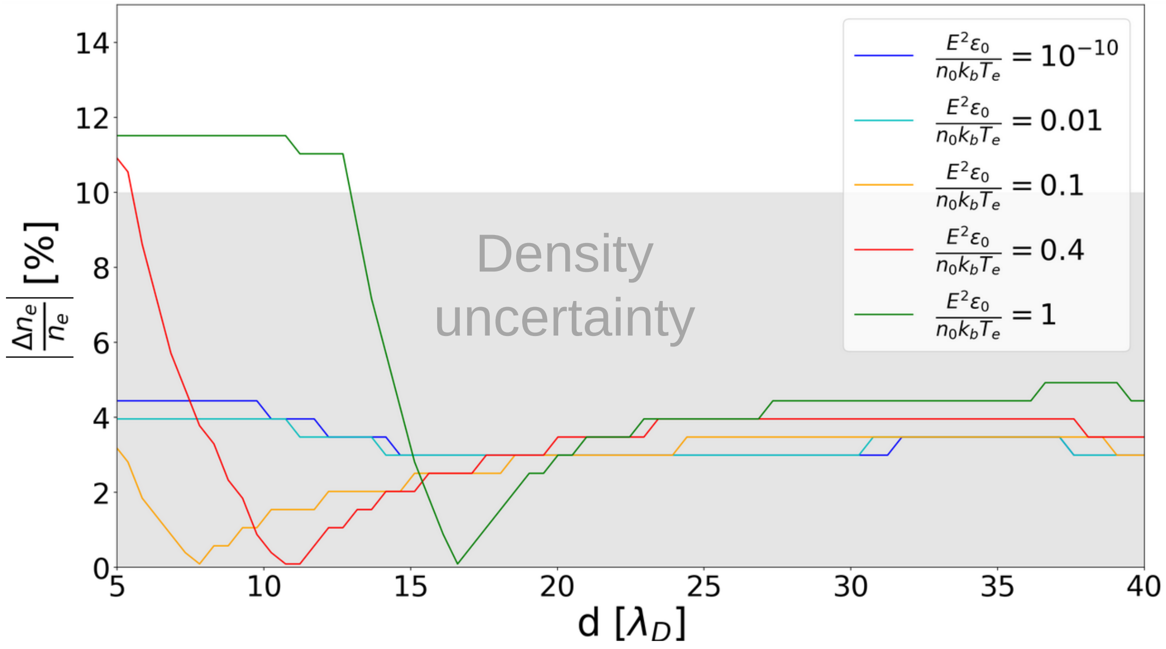


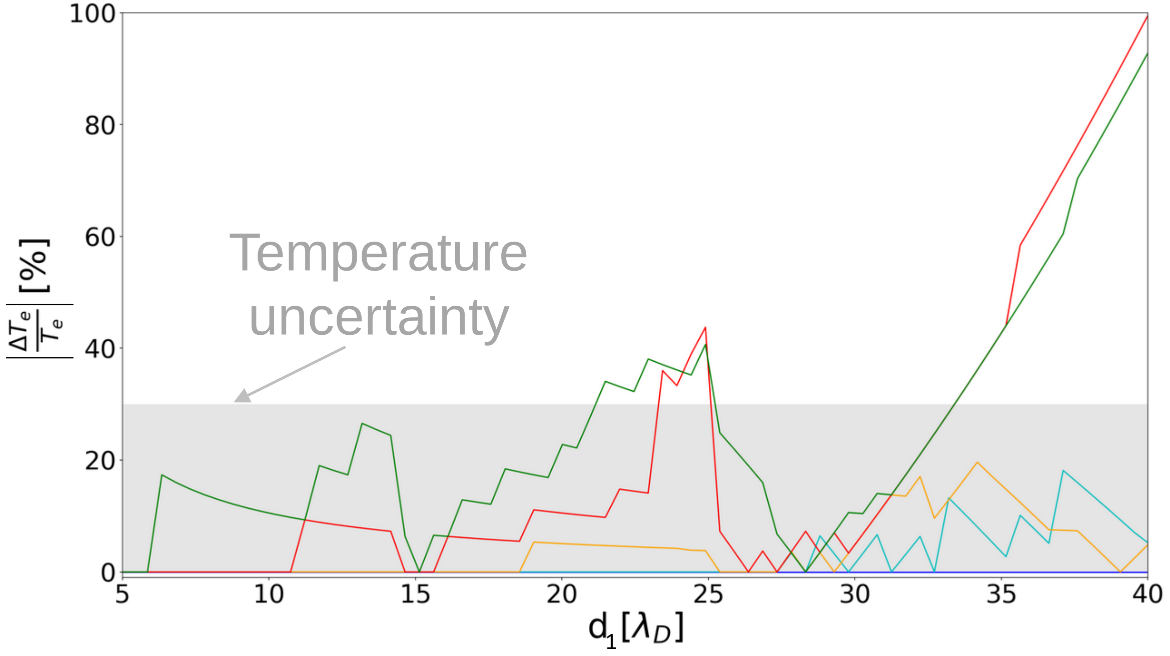
Linear

Non-Linear

To be submitted

3) Effects of large emission amplitudes





Frequency resolution = 5% → Plasma density uncertainty = 10%

Plasma density:

→ the identification procedure <u>is robust</u> to strong emission amplitudes

Electron temperature:

→ <u>robust for</u> — $\frac{E^2\varepsilon_0}{n_0 k_b T_e} = 0.1$

(Conservative) conclusion:

→ <u>ok for</u> $\frac{E^2\varepsilon_0}{n_0 k_b T_e} = 0.1$

To be submitted

3) Minimization of antenna occupation time

Ongoing work

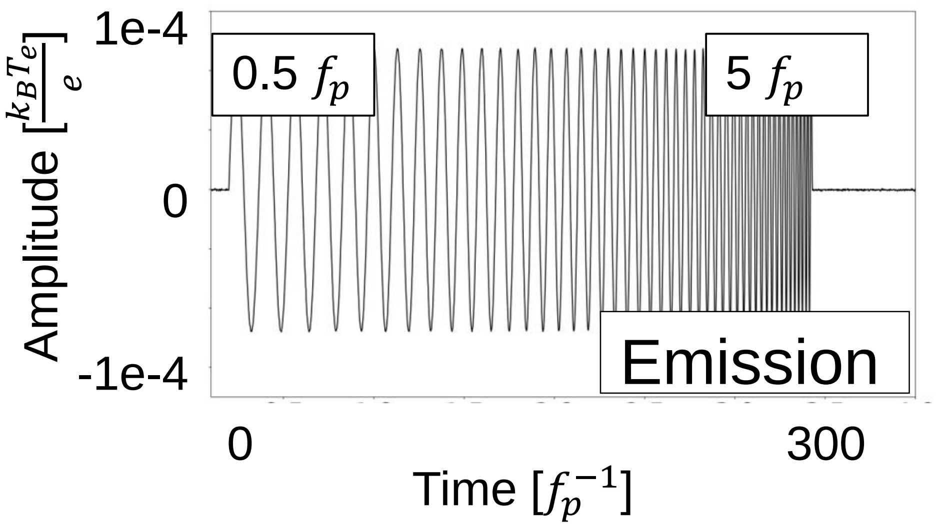
Objective:
Reduce the mutual impedance antenna occupation time

- **Signal duration:** $\boldsymbol{T_f = \frac{N}{f}}$
- Frequency range
- Frequency resolution

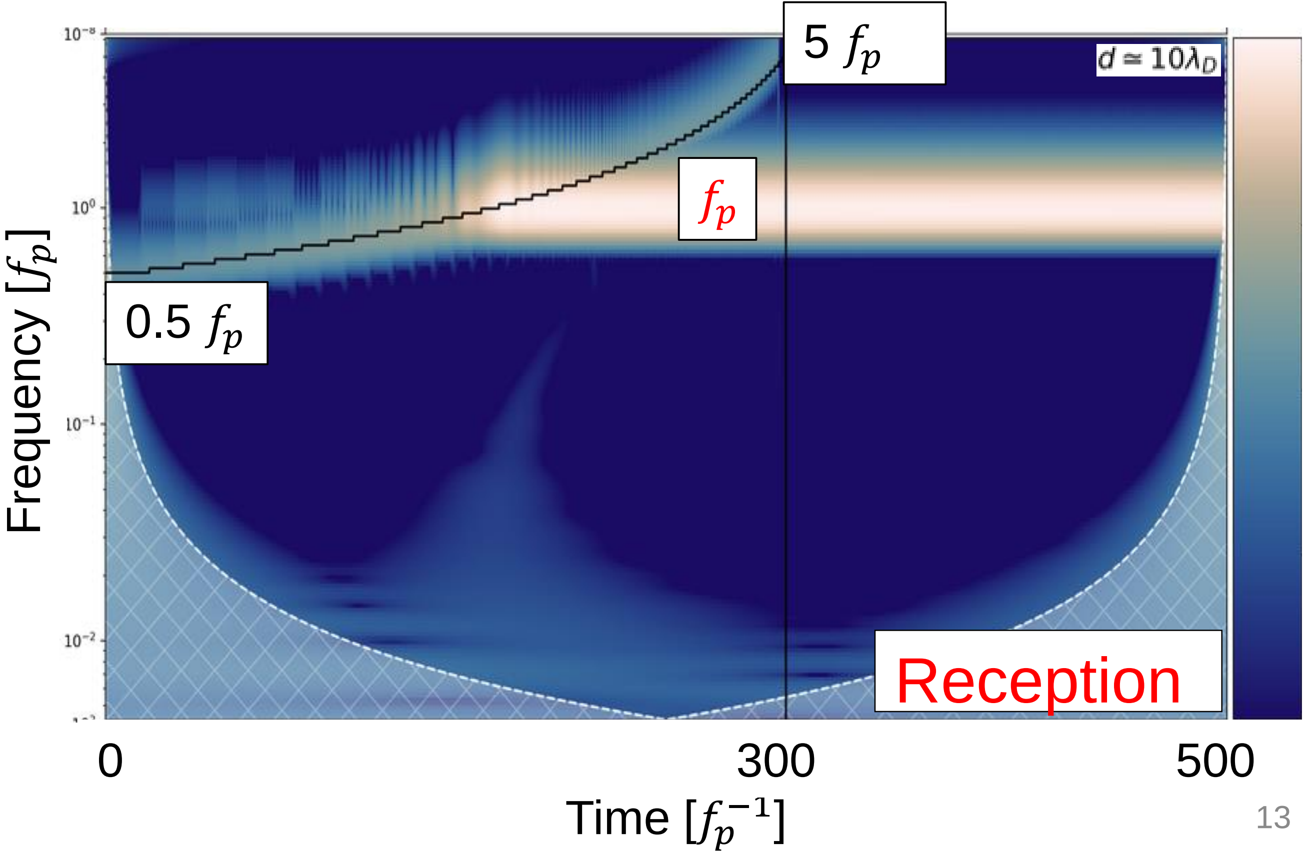
Experimental applications: **N=10-100**
New mutual impedance instrumental mode:
Chirp mode → N=1

Numerical part of the investigation

(Full kinetic Vlasov Poisson 1D-1V)



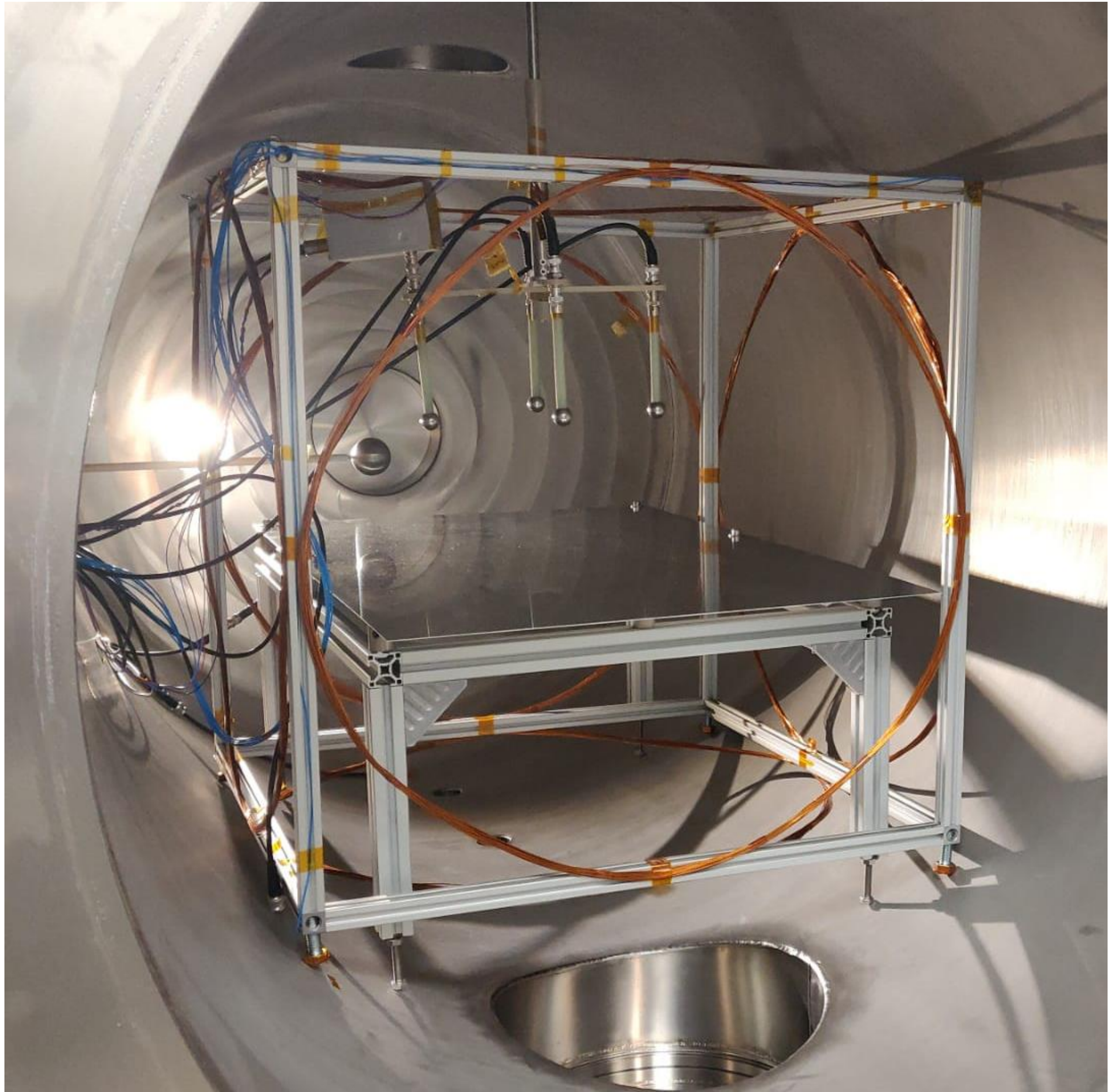
Continuous Wavelet Transform (Morlet window function)



3) Minimization of antenna occupation time

Ongoing work

Experimental part of the investigation



Experimental configuration:

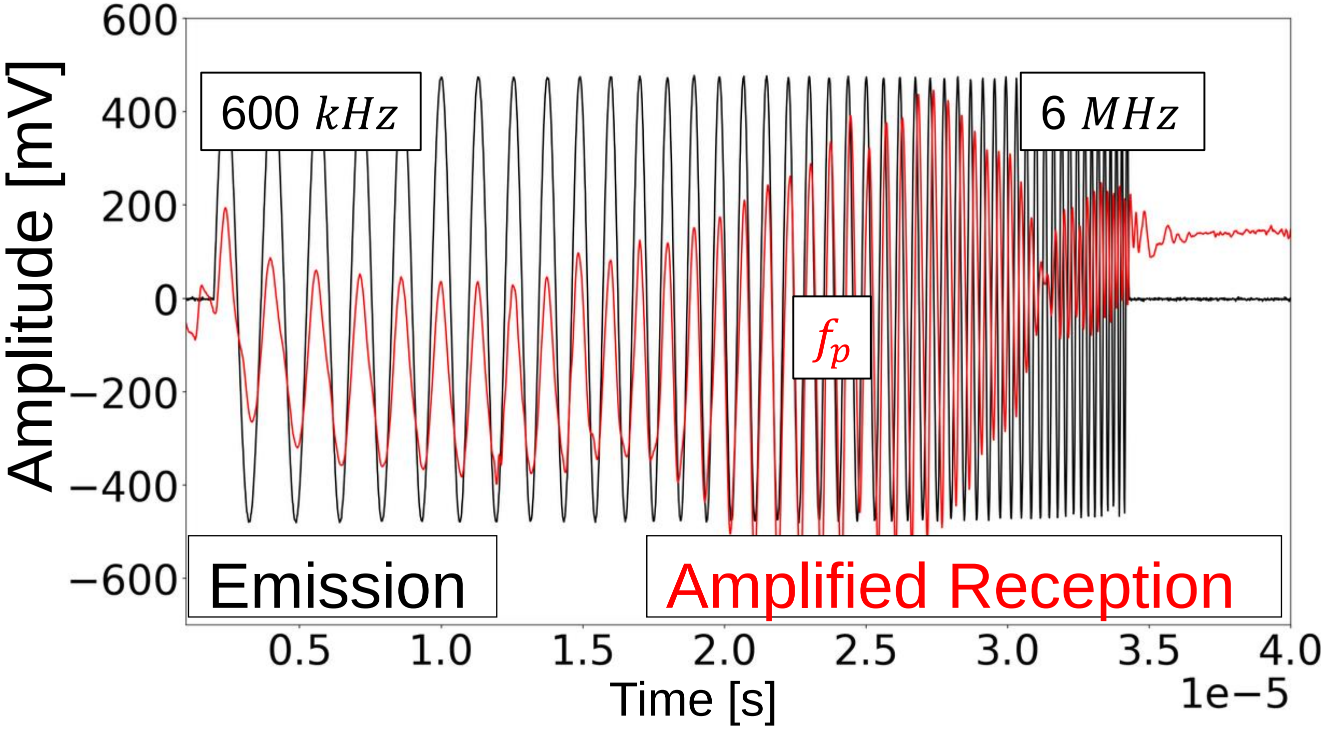
- Emitting plate (1D-like electric field)
- Receiving spheres
- Magnetic field compensation

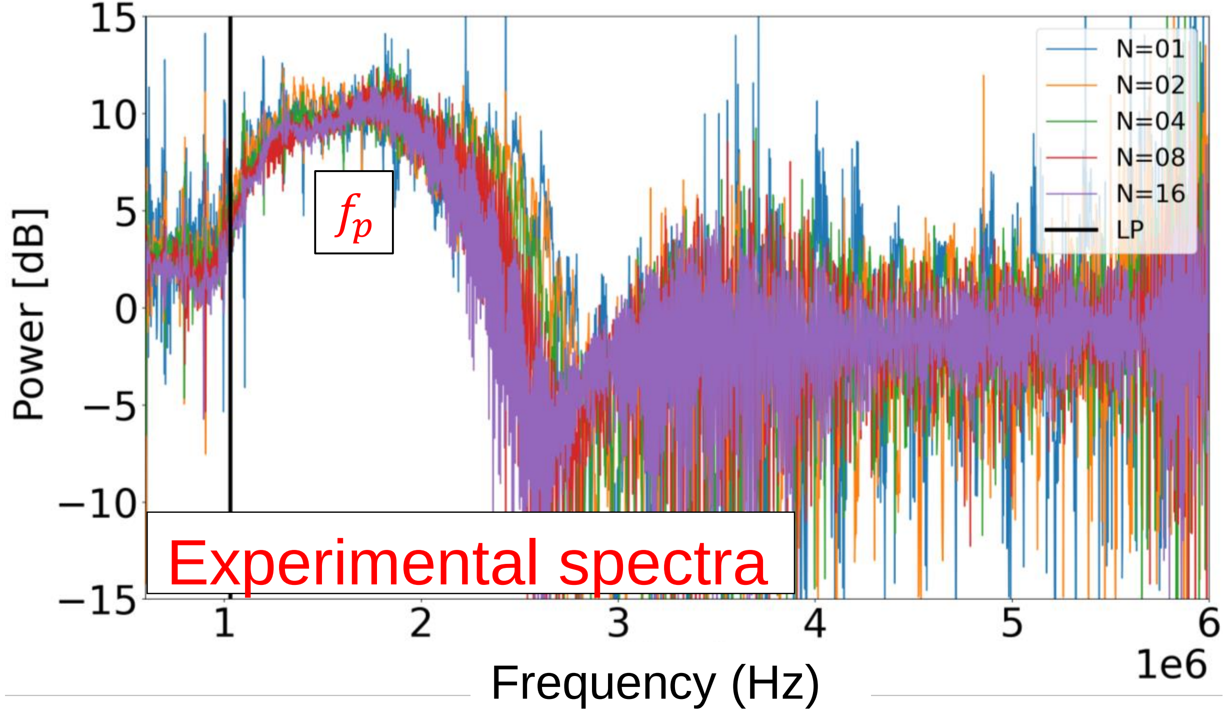
3) Minimization of antenna occupation time

Experimental part of the investigation

Ongoing work

Signal duration: $T_f = \frac{N}{f}$





Experimental waveforms of the emitted and received electric signals

Spectra **normalized to** corresponding **vacuum** spectra

Next step:

→ assess the diagnostic performance from the spectra

Conclusions

- What is the maximum emission signal amplitude?

$$\frac{E^2\varepsilon_0}{n_0 k_b T_e} = 0.1$$

Thanks!

Questions?

- What is the minimum emission signal duration?

N=1 (plasma density, electron temperature)

Signal duration: $T_f = \frac{N}{f}$